EQUILIBRATION AND ITS RELATION TO VERTIGO.[1]

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The following physiological considerations may be regarded as preliminary to a future discussion of the origin and mode of development of the various forms of vertigo. The chief point of this article is an attempt to show the importance of the relation of the cortical centres to the act of equilibration.

Vertigo is essentially a psychical phenomenon and may be defined as the consciousness of a disturbance of the body equilibrium. The maintenance of equilibrium represents the action of those forces in the organsim having to do with the preservation of the position of the body in space. This preservation of the body equipoise is only one of the acts comprising the general process of equilibration which consists of the balancing of all forces operating in the organism. These forces are called functions, and equilibration, therefore, in its broad philosophical significance is the maintenance of the physiological balance. Frequently, however, the term "equilibration" is used in a restricted sense as meaning simply the act of maintaining the equilibrium. Thus limited and defined, the expression will be more convenient, and for the present purpose will be so employed.

Under normal conditions the act of maintaining the equilibrium is carried on automatically and independently of consciousness, and it is only when there occurs a defect in the mechanism of the process that we become conscious of the result of its defective operation. This result is that peculiar sensation called giddiness or dizziness, or when

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the sensation is more intense, it is termed vertigo. At no time are we conscious of the process of equilibration either in its defective or normal action. We are conscious only of the results of this action, which in the case of defective equilibration is the sensation of vertigo, and in the case of normal equilibration is the sensation of maintained equilibrium. Ordinarily, this latter sensation is not perceived in consciousness unless it is made the object of special attention. When this is done the act of equilibration ceases to be automatic and becomes in part voluntary, that is, it is associated with consciousness and, therefore, may be said to have a psychical element. The simplest kind of action which will illustrate the operation of this psychical element is that of voluntary body balancing. In such effort the action of muscle in correspondence to sensory stimuli does apparently yield distinct sensations which can best be described as those of lost or maintained balance. It is also possible to conceive of these acquired reflex sensations as of frequent occurrence in the consciousness of a child learning to walk. As the motor adjustment to the sensory stimuli becomes more perfect, the resulting sensation grows less vivid in consciousness until, finally, by constant repetition, the act of equilibration, like the act of coordination, with which it is closely associated, becomes purely automatic. The term automatic, rather than reflex, is used to denote that the act is a complex of reflex acts and may be subject to modification by intercurrent cortical influence.

In this act of body balancing, which represents the mildest form of equilibratory disturbance, there is no true vertiginous sensation. Such sensation as does exist is the result of a series of sensori-motor processes, each short, complete and successful in its alternating loss and recovery of the body equipoise. If we were to imagine a rapid succession of ineffectual attempts to regain the body balance, then the sensation of vertigo would arise in consciousness.

The act of maintaining the body equilibrium or equilibration, using the term in its restricted sense, as an organic process is dependent not upon the operation of a special equilibratory apparatus or centre, such as has been suggested to exist in the semi-circular canals and cerebellum, but upon the operation of all parts of the general sensory-motor system which in any way subserve the process in question. The action of these parts is not separate and distinct, it is combined, and yet the impairment or abscence of one or more parts does not necessarily destroy the general function, it simply limits its extent and power. Thus, admitting the importance of the part played by the semi-circular canals, it is noted that their destruction does not aparently interfere with the continuance of satisfactory equilibration.

Likewise, loss of vision and impairment of the tactile sense may occur, and yet the body equipoise be maintained. Indeed, it is possible to conceive that all sensory stimuli may be diminished to the point of barely permitting the simplest motor co-ordinations, and still consciousness be not aware of disturbance of the equilibrium. Experiments with animals have shown that the function of equilibration may still persist after the removal of the cerebral hemispheres. This fact clearly demonstrates that consciousness is not an essential factor in the act. It is also certain that the cutting off of all sensation would render the phenomenon of vertigo impossible. The severest attacks of vertigo occur only when the sensory paths are in a condition to transmit powerful, but perverted stimulations to encephalic centres.

While there need not be, therefore, and commonly is not, a psychical element in equilibration, it is nevertheless true that in man this act in its very highest development may be considered not a purely physiological but a psycho-physiological affair. And viewed as automatic, it may be said to be by a species of retrogressive development the result in part of conscious or voluntary acts. Thus, in the child learning to walk, or in feats of body balancing, the acts become automatic by practice, *i. e.*, by repetition, and what are largely voluntary acts, executed at first with the aid of consciousness, gradually lose their psychical concomitant and become automatic.

In the act of locomotion, which is an allied sensori-motor mechanism to that of equilibration, the psychical element is present to a greater degree. Yet it is constant experience that the act of locomotion once thoroughly inaugurated is frequently carried on apparently automatically, that is independently of consciousness for short periods at least. Equilibration is not only associated with locomotion, it also underlies it as a primary function. Locomotion cannot occur without equilibration, and on the other hand locomotion is not essential to equilibration, as it is conceivable for an individual to maintain the balance without being able to walk. The fitness and advantage of equilibration becoming automatic is obvious from the fact that no act of such constant and fundamental importance could have a psychical concomitant without seriously embarrassing the efficiency of action. In other words, conscious effort to adjust the body after each change of position would subject all movements to delay and imperfect execution.

Considering now the purely physiological side of equilibration, we find that the act consists of the operation of three sets of factors.

First, peripheral end organs with their afferent nerves conducting sensory stimuli.

Second, co-ordinating centres receiving these stimuli.

Third, efferent nerves from these centres conducting motor impulses to the skeletal muscles.

The first group of factors represents sensory stimuli arising from all sources in the periphery which are capable of yielding directly or indirectly sensations of the positions of the body. The three chief sources of these stimuli are, first, organs and nerves in the skin receiving and transmitting tactile impressions. Also grouped with this class are the sensory nerves of the muscles, tendons, ligaments and joints which transmit impressions indicating the position of the limbs or body as a whole. This is the so-called muscular sense.

Second, the eyes with their retinal expansion receiving and transmitting visual impressions through the optic nerve.

Third, the semicircular canals of the internal ear receiving and transmitting through the vestibular branch of the auditory nerve stimuli, which indicate the position and balance of the head, and less directly play a part in the precision of movement and general state of equilibrium throughout the body.

The coordinating centres, located chiefly in the mesencephalon and cerebellum, are the second factor in the act of equilibration. Animal experimentation and pathological conditions in man show the connection of those centres both with the cortex above and the lower centres in the spinal cord. On one hand, following injury or absence of the hemispheres, the subcortical centres are seen to functionate satisfactorily for all simple peripherally initiated acts of equilibration, while the complex or originating acts fail of execution. On the other hand, injury to the mesencephalic or cerebellar centres causes direct and more or less permanent impairment of the simple as well as complicated acts of equilibration.

The third factor is the system of efferent nerves from these centres carrying motor impulses which excite muscular action, thereby adjusting the position of the body in accordance with sensory stimuli previously received.

The imperfect operation of any part or the whole of this triple mechanism may give rise to a vertiginous sensation which will correspond to the degree and extent of the disturbance of this mechanism. In the order of importance the coordinating centres take precedence over the other factors, and it may be stated that unless the disturbance in any part of the mechanism also involves these centres no vertigo will result. They preside, as it were, over the functions of equilibration, and on their integrity depends the success of adjusting the efferent motor impulses to the afferent stimulations. These centres are subject to two classes of impulses, first, the peripheral afferent stimuli, and secondly, influences from the higher cortical centres, which, may modify or interrupt their action. In the case of absence or perversion of stimuli from any point in the periphery, *e. g.*, the eye, we note that the coordinating centre accommodates itself to the deficiency and carries on the mechanism for all ordinary acts of equilibration nearly as completely as before. The cortical or psychical influence on the equilibrial centres is seen under emotional conditions.

The efferent nerves are the least important factor in the general mechanism of equilibration. They, and the muscles they innervate, may be subject to serious disorder, and yet no vertigo result unless the coordinating centres from which the impulses are derived are likewise disturbed. This is seen in advanced ataxia. The movements of the legs may be so imperfect and uncertain that the patient cannot stand or walk, and yet no vertigo results because the sensation of lost balance ceases when the effort stops. The sensation of disturbed, or lost, balance must persist in consciousness in order to produce vertigo.

Pursuing in brief detail the study of the sensory stimuli on which the integrity of the equilibrial centres in the main depends, the truth of the assertion that the act of equilibration is of compound and not simple nature, is soon made evident. Considering first the influence of tactile and muscular sense impressions, it is noted that removal of the skin of the hind limbs of the frog, or Heyd's experiment in man of benumbing the cutaneous nerve endings in the soles of the feet by chloroform, results in difficulty in standing and keeping the body balance. In locomotor ataxia we have the combined effect of impaired tactile sensibility and also disturbed joint-muscular impressions resulting from the ataxic condition. In maintaining the equilibrium the ataxia is relatively of less importance than the loss of skin sensibility. That is, the ataxia may be pronounced without marked equilibrial disturbance, and *vice versa*, the equilibrium may be greatly disturbed without ataxia. With the loss of tactile sensibility, say of the soles of the feet, however, there always occurs difficulty in balancing the body, and the amount of this difficulty seems to depend more upon the degree of impaired tactile sensibility than upon the degree of ataxia.

The effect of visual stimuli upon the above phenomena is very distinct, and shows the intimate relation existing between the tactile and muscular sense. In every instance the difficulty of maintaining the balance is immensely lessened provided the eyes remain open. Within certain limitations the impairment of both the tactile and muscular sense may be compensated for by the visual sense. The simple standing erect of the ataxic individual with eyes alternately open and shut will illustrate the close association of the two kinds of stimuli in their effect upon the equilibratory centres. In the blind the absence of visual impressions requires the higher development of the tactile and muscular senses, with a consequent much greater dependence upon stimuli of this character. But in the normal individual the two sets of stimuli are developed together, the eyes noting the point of contact and following the movement of the limbs in the various positions assumed independently, or in relation to external objects.

Visual stimuli may exert a disturbing effect upon equilibration in two ways. First, by the unusual movement and relation of objects in the field of vision, such as is experienced, on moving trains, or in regarding those passing, in .watching swiftly running water, in looking over a precipice, etc. The visual impressions arising from the extraordinary relation of external objects demand new and uncommon efferent impulses which the equilibrial centres are not capable of furnishing. Hence, a failure in the motor adjustment to the afferent stimulation results, and consequent upon this failure there arise in consciousness feelings of insecurity, of abnormal body position and space relationship, of imperfect balance and dizziness.

Secondly, these same sensations may be experienced following perverted visual impressions dependent upon the defective operation of the oculomotor mechanism. The condition of nystagmus, or of paralysis of the external rectus muscle of the eyeball, yields disturbed visual impressions which produce the feelings in consciousness mentioned above.

Passing now to the consideration of the semicircular canals we come to the most important factor in the maintenance of equilibrium. Without attempting to define the exact nature of the semicircular canal stimuli, it will be sufficient to say that there is no reasonable doubt among physiologists that such stimuli exist, and that they play a part in the movements of the head and body, particularly in regard to the precision and equilibration of the muscular acts. The evidence of this function is derived through experimentation upon the canals in animals, and the pathological and functional disturbances of the ear in man. The work of Flourens and subsequent investigators is sufficiently convincing, and the disturbance of the equilibrium associated with affections of the ear in the symptom-complex, called Méniére's disease, is unmistakable proof of disordered semicircular canal stimuli. It has been argued that these canals can not be such an important factor in equilibration as claimed, because we are so unconscious of their operation. It is true that the stimuli arising in the canals and carried by the vestibular nerve do not excite sensations such as result correspondingly to the visual or tactile stimuli, but this very fact may be said to indicate the deeper and vital nerve function of these organs. The acts of respiration, circulation and digestion under normal conditions yield no sensation. Similarly if we consider what a fundamental and vital process the act of equilibration is, how it lies at the very bottom of organic stability and the preservation of the body in space, then it is easy to see how the function should be independent of consciousness. It is a function, too, which has existed from the moment of birth, and, viewed psychologically, must have been present in an incipient degree previous to the development and incorporation of its visual and tactile factors. In considering the cutaneous sensations, it is possible to conceive that the atmosphere may produce by pressure upon the tactile endorgans continuous inflowing stimuli, which by reason of their constant and familiar existence fail to develop sensation. If a change in this pressure occurs beyond the ordinary limits, then the stimulus yields a sensation. In a similar manner one can conceive of the normal unconscious influx of stimuli from the semicircular canals. The ordinary atmospheric pressure without in conjunction with a given state of the endolymph of the canals—which is also subject to internal variations from moment to moment, owing to the position and movements of the head—may produce stimuli which affect the coordinating centres below the level of consciousness. If now the external pressure varies, being markedly increased or decreased, as occurs by forcing air in the ear, or in a caisson, or if the internal condition of the canal contents departs from the normal, *e. g.*, by sharp change in the tension due to circulatory disorder, then a variation occurs in the character of the canal stimuli. There is this difference, however, between the change of stimuli of the skin and canals. In the former we are directly conscious of the change, as interpreted by corresponding sensations, *viz.*, touch or pressure. In the latter instance, by virtue of the change in stimuli, we are conscious of sensation corresponding to the stimuli, but of a totally different sensation, *viz.*, dizziness which cannot be traced directly to the canal stimuli.

This dizziness may be compared in character to the sensations of hunger, thirst, and nausea, which cannot be directly connected in consciousness with the stimuli originating them. All of these sensations are complex in nature, and there does not exist the simple immediate relation between the stimulus and sensation as in the case of pressure on the skin. Although of such a general and indefinite character, they are all more or less referrable to that region of the body from which the stimuli come. Thus, thirst is referred to the mouth and throat, hunger and nausea to the stomach. The diminution of water in the cells of the mucous membrane of the mouth, tongue and pharynx may generate stimuli which are the chief factor in the production of a general body condition which is represented in consciousness as the feeling of thirst. In like manner, hunger and nausea may arise from the alterations in the gastric mucous membrane. In dizziness, especially of pronounced degree, aural symptoms are almost always present, but the condition is so general, involving, as it does, both visual and tactile factors, that the individual fails to refer it to the ear.

While the semicircular canals are undoubtedly a factor of most unique and special character in the act of equilibration, it is still true that their absence or destruction does not prevent the maintenance of the equilibrium. Animals deprived of their canals show marked impairment in their equilibrating power which is never fully recovered.

In deaf mutes and persons who have suffered from destructive lesions of the labyrinth, vertigo is a rare symptom, and cannot be induced experimentally with anything like the frequency that it can in normal individuals. The loss of the semicircular canal stimuli is compensated for in great part by the visual and tactile stimuli, but the complex and highly developed acts of equilibration are not possible, and the capacity of the individual to experience vertigo is correspondingly decreased.

As stated at the outset, under ordinary conditions equilibration is an automatic process, but it has been shown that whenever it is associated with conscious effort, it necessarily acquires a psychical element. That it is possible to introduce this psychical or subjective element at all times becomes apparent when we consider that the afferent sensory stimuli necessary to the act of equilibration are the same as those which yield the sensation of position in consciousness, that is, we are conscious from moment to moment of our position in space, and the relation of the body to external objects. Indeed, it may be said that equilibration depends for its existence on the combined action of stimuli which occasion sensations of position and sensation of motion, but we do not commonly make any conscious application of these sensations in the execution of the act. These afferent stimuli, therefore, may be said to have a two-fold effect, one is the production of pure sensations of position, and the other is the concomitant exciting of centres below consciousness, whereby the body equilibrium continues to be preserved. It is probably, as sugested in the early life of the child, that the sensations of position were made use of as a psychical factor in the act of equilibration, but gradually, as the act became more perfect, *i. e.*, more automatic, these sensations ceased to be necessary as being consciously related to the act. If the maintenance of the equilibrium can be defined as the action of those forces in the organism having to do with the preservation of the position of the body in space, then the consciousness of a disturbance of equilibrium, or vertigo, may be interpreted as the consciousness of a disturbance of the body position. This definition of vertigo is, indeed, correct with the qualification that the disturbance is of a peculiar kind. It is not every disturbance or change of the body position which is temporary and due to inadequate motor acts, but rather a permanent disturbance both of the cortical and subcortical nerve centres, due to the continuous influx of disordered sensory stimuli from the periphery. The individual, therefore, becomes doubly conscious of disturbed spacial relation, primarily, as the direct result of the distorted sensory stimuli on the cortex, and secondarily, as the result of the disturbed equilibrium or its equivalent disturbed body position which is occasioned also by these same stimuli acting through the medium of the subcortical centres. The actively disturbed body equilibrium, therefore, may be considered as representing the motor side, or motor expression, of the disturbed condition of both the cortical and subcortical centres.

Stimulation of the optic, auditory, and nerves of general sensibility give rise constantly to sensations of position when the body is at rest, and equilibrium can become actively associated with these sensations only when the body is under the tension of the act, either in the erect position or motion. Hence, in the passive condition of the body, sensations of position are developed through purely sensory stimuli, in the active state of the body, the same stimuli are in operation plus the motor adjustment necessitated by them, but without the development of sensations as far as this specific adjustment is concerned. In the latter instance of the body in motion, the equilibrium which is maintained may be termed dynamic, in the sense of being dependent largely upon motor effort; in the former instance, when the body is at rest, the equilibrium is almost purely psychical, and may be designated as static, being dependent upon normal sensory stimuli but without motor excitation.

The result of this excitation or adjustment is present in consciousness as the sensation of maintained equilibrium or body position, and if this adjustment is imperfect and continuous, then sensations of disturbed body position are the chief feature of consciousness. Hence, summing up the act of equilibration in its entirety, it would seem justifiable in considering it a psycho-physiological process, to define its psychical element as the consciousness of body position, while the muscular adjustment maintaining this position represents the motor element of the same process. Certainly, in vertigo we have, on the one side, the consciousness of disturbed body and spacial relationship, and on the other, the consciousness of unavailing motor efforts to rectify this relationship.

Most writers on the subject of equilibration and vertigo have emphasized the physiological side of the problem, and it has seemed to the author that the failure to recognize the importance of the psychical element has prevented the full understanding of the nature of vertigo. The fact that equilibration can, and ordinarily does occur, independent of consciousness, has led to the ignoring of the influence and connection of the cortex with the act. It seems to have escaped notice that the integrity of the act depends almost as much upon the condition of the cortical as upon the mesencephalic and cerebellar centres. Thus, if the psychical centre, or consciousness, is clear, equilibration is perfect; if consciousness is clouded or disturbed from the normal condition, then equilibration is, or may be imperfect, depending upon the character of the cortical disturbance. As far as equilibration is concerned, consciousness may become clouded in two ways: directly, by the reception of disturbed sensory stimuli yielding sensations of disturbed body position, as is the case of true primary vertigo; or indirectly, by the occupation of the whole field of consciousness by other sensations to the exclusion or modification of its normal space and position attributes. This latter condition occurs under strong emotion, shock, pain, or the effect of an idea. The dizziness or loss of the sense of position which accompanies this condition of consciousness results, primarily, not from disturbed sensory stimuli, but from the more or less complete absorption of consciousness in some powerful impression made upon it. Consciousness is preoccupied, and the sensory stimuli fail to produce their natural effect; they are negated, and consciousness, therefore, is without its usual statical attributes. The vertigo associated with gastric disorders, cranial nerve crises, emotional states, or whenever present and not originally due to perverted position stimuli, can only be satisfactorily explained by recognizing the cortex as a factor in the function of equilibration

The ground or basis for advocating the importance of the condition of the cortex in the act of equilibration, and as related to the production of vertigo, is the principle of psycho-physiology so ably developed among English medical writers, by Hughlings-Jackson, and supported by the anatomical and embryological researches of Flechsig, *viz.*, that all parts of the body have a representation in the cortical centres, and conversely, that these centres may exert an influence on all these parts. Also, in connection with this principle is the accepted fact that all ideas or sensations tend to express themselves, so that whatever the state of consciousness may be, there exists a constant tendency for it to be manifested outwardly.

The understanding of this principle of cortical influence, the writer believes, is the key to the explanation of all forms of vertigo which arise outside of the primary involvement of the special sensory stimuli which yield sensations of position.